Description

STEAM POWERED FREE PISTON PUMP

Technical Field

[01] This concept relates generally to a system wherein a free piston pump is actuated by steam power, and more particularly to applying clean and environmentally friendly steam technology in place of a compression ignition system.

Background

[02] Past practice has used steam power to expand a turbine and convert the steam power to mechanical power for driving other implements such as a generator, a pump or mechanical drive such as a transmission. Other systems have converted fuel energy to mechanical power, such as diesel fuel energy to hydraulic power.

[03] A present day application is disclosed in U.S. Patent Number 3,990,243 issued to John Gordon Davoud on November 9, 1976. The above identified system or cycle discloses a steam or other condensable vapor being heated to a maximum temperature at a maximum pressure and being permitted by the system to expand to a lower pressure in a positive displacement expander. The expanded fluid is then further expanded in a turbine. A portion of the fluid in the turbine is withdrawn and directed to a positive displacement compressor and compressed to the maximum operating pressure while introducing the condensate of the remaining portion of the vapor into the compressor. The compressed fluid is then reheated to maximum temperature and the cycle is repeated.

[04] What is needed is a design which economically and environmentally converts fuel energy to drive other implements.

[05] The unique design included herein converts a clean and environmentally friendly steam technology in place of a compression ignition system. The design allows an improvement over existing compression ignition systems and can utilize a super low emission external combustion system as a power source which operates at a greater efficiency and decreases fuel consumption via regeneration. Unlike the turbine expander, the present system does not require steam of quality 1 and can expand the steam until the quality drops below 1 into the region of saturated vapor. This adds to the potential efficiency by extracting more energy from the steam in the system.

[06] The system converts steam power to hydraulic power. And, to insure maximum efficiency saturated steam and water are uniquely removed from the steam power converting source.

[07] The present invention is directed to overcoming one or more of the problems as set forth above.

Summary of the Invention

[08] In one aspect of the invention, a system is operated by an outside source of fluid and produces hydraulic power. The system is comprised of a free piston pump being operated by the outside source fluid and a control system. The free piston pump is operated by the outside source fluid. The free piston pump has a housing having a pair of chambers positioned therein, a pair of end covers having a pair of chambers therein, a first valve being operatively attached to one of the pair of end cover. The first valve is movable into an open position fluidly connecting the fluid with one of the pair of chambers. A second valve is operatively attached to another one of the pair of end covers. The second valve is movable into an open position fluidly connecting the fluid with another one of the pair of chambers. At least a single piston is slidably positioned in at least one of the pair of chambers. A shaft is attached to the piston and has a first end being

slidably positioned in one of the pair of chambers. A control system includes a computer, a plurality of sensors being attached to the free piston pump, and a plurality of lines interconnecting the sensors and the computer.

[09] In another aspect of the invention, a free piston pump is operated by an outside source fluid. The free piston pump comprises a housing having a pair of chambers positioned therein; a pair of end covers having a pair of chambers therein; a first valve being operatively attached to one of the pair of end cover, the first valve being movable into an open position fluidly connecting the fluid with one of the pair of chambers; a second valve being operatively attached to another one of the pair of end covers, the second valve being movable into an open position fluidly connecting the fluid with another one of the pair of chambers; a pair of pistons, one of the pair of pistons being slidably positioned in each one of the pair of chambers; a first shaft being attached to one of the pair of pistons, the first shaft having a first end being slidably positioned in one of the pair of chambers; a second shaft being attached to another of the pair of pistons, the second shaft having a first end being slidably position in another one of the pair of chambers.

[10] In another aspect of the invention, a method of operating a system wherein a free piston pump receives power from an outside source of fluid, the free piston pump has a piston positioned in a chamber and a shaft positioned in another chamber comprises the steps of: sensing a plurality of positions of the piston within the chamber with a plurality of sensors; sending a signal from the plurality of sensors to a computer; directing the fluid to the chamber; moving the piston within the chamber; causing the shaft to move within the another chamber; and displacing a high pressure fluid from the another chamber.

Brief Description of the Drawings

[11] Figure 1 is a diagrammatic and systematic view of a system for operating the present unique design disclosing a free piston pump;

[12] Figure 2 is a diagrammatic and systematic view of a system for operating the present unique design disclosing an alternative for the free piston pump disclosed in Figure 1;

[13] Figure 3 is a further example of a free piston pump having different sized pistons;

[14] Figure 4 is an example of a simple Rankin T-s diagram describing the operation of the system; and

[15] Figure 5 is a T-s diagram of a proposed steam operating cycle.

Detailed Description

[16] Referring now to Figure 1, a system or means for converting 6 steam or another condensable vapor or fluid as a power source to hydraulic power is shown. The system 6 includes a source of condensable vapor or fluid 12, a free piston pump or means for pumping 14, a plurality of tubes or passages 16 for interconnecting the fluid 12 with the free piston pump 14, a plurality of tubes or passages 18 for exhausting the fluid 12, a plurality of tubes or passages 20 for transporting a high pressure fluid, hydraulic power, 22 exiting from the free piston pump 14 for external use outside the system 6, a plurality of tubes or passages 24 for transporting a low pressure fluid 25 for internal use within the system 6 and a plurality of valves 26 make up the system 6. The system 6 also includes a control system or means for controlling 28.

[17] The fluid 12 within the disclosure is also designated as a means for a power source, the free piston pump 14 is also designated as a means for pumping, the plurality of tubes or passages 18 for exhausting the fluid 12 is also designated as a means for exhausting, the plurality of tubes or passages 20 for transporting a high pressure fluid 22 is also designated as a means for transporting a high pressure fluid 22, the plurality of tubes or passages 24 for transporting a low pressure fluid 25 is also designated as a means for transporting a low pressure fluid 25 and the plurality of valve 26 is also designated as a means for valving.

[18] The source of condensable vapor or fluid 12 is supplied externally by a plurality of methods, such as from a fuel burning steam boiler or a cogeneration system, diesel exhaust reheat or gas turbine exhaust reheat. However, as an alternative the fluid 12 source could be a direct part of the system. The free piston pump 14, in this application, includes a housing 30 defining a first end surface 32, a second end surface 34 and at least one side surfaces 36. For example, if the housing 30 is cylindrical there will be only a single side surface; however, if the housing 30 is rectangular there will be four side surfaces, etc. A bore 38 is positioned within the housing 30 and extends between the first end 32 and the second end surface 34. The bore 38 has a preestablished circumferential configuration, which in this application is generally cylindrical and substantially circular. As an alternative, the bore 38 could be elliptical, rectangular or any other configuration without varying the gist of the design. A plurality of threaded bores 40 having a preestablished geometrical configuration are threadedly positioned in each of the first end surface 32 and the second end surface 34. A pair of end covers 50 each define a first surface 52 and a second surface 54 being spaced one from the other a preestablished distance. A plurality of through bores 56 having the same preestablished geometrical configuration of the plurality of threaded bores 40 extend between the first surface 52 and the second surface 54 of each of the pair of end covers 50. The first surface 52 of one of the pair of end covers 50 is in contacting sealing relationship with the first end surface 32 of the housing 30. And, the first surface 52 of the other of the pair of end covers 50 is in contacting sealing relationship with the second end surface 34 of the housing 30. A plurality of fasteners, such as bolts 60 removably attach the respective one of the pair of end covers 50 to the housing 30. As an alternative, a plurality of through bores and bolts or threaded rod could be used in place of the bolts 60 and threaded bores 56 to removably fasten the housing 30 with the pair of end covers 50. As a further alternative, at least one of the pair of end covers 50 could be integral with

the housing 30 or fixedly attached thereto. In this application, the surface finish of the first end surface 34 of the housing 30 and the first surface 52 of the pair of end covers 50 and the second end surface 36 of the housing 30 and the first surface 52 of the pair of end covers 50 respectively seal the pair of end covers 50 with the housing 30. As an alternative, a gasket may be interposed the pair of end covers 50 and the housing 30. Each of the pair of end covers 50 has a blind bore 62 extending from the first surface 52 toward the second surface 54. The blind bore 62 has a preestablished diameter and defines a bottom 64. A shaft 70 having a preestablished configuration which in this application is designed as a diameter. The blind bore 62 defines a first end 72 and a second end 74. A piston 76 having a preestablished circumferential configuration to match that of the bore 38 in the housing 30 is positioned on the shaft 70 intermediate the first end 72 and the second end 74 of the shaft 70. The piston 76 defines a first surface 78 and a second surface 80 being spaced one from the other a preestablished distance. The first end 72 of the shaft 70 is slidingly positioned in blind bore 62 of one of the pair of end covers 50, the piston 76 is slidingly positioned in the bore 38 and the second end 74 of the shaft 70 is slidingly positioned in the other one of the pair of end covers 50. In this application, a seal 82 is interposed the shaft 70 and the blind bore 62 near the first surface 52 in each of the pair of end covers 50. And, a seal 84 is located intermediate the first surface 78 and the second surface 80 along the circumferential contour. Thus, with the piston 76 positioned in the bore 38, the seal is interposed the piston 76 and the bore 38 in the housing 30.

[19] A first chamber 86 is formed between one of the first surface 78 or the second surface 80 the piston 76 and the first surface 52 of one of the pair of end covers 50 and a second chamber 88 is formed between the other of the first surface 78 or the second surface 80 of the piston 76 and the first surface 52 of the other one of the pair of end covers 50. A third chamber 90 is formed between the first end 72 of the shaft 70 and the bottom 64 of the respective blind bore 62. A

fourth chamber 92 is formed between the second end 74 of the shaft 70 and the bottom 64 of the respective blind bore 62. The first chamber 86 and the second chamber 88, with the piston 76 spaced from the first surface 52 an equal distance, has an equal preestablished volume. And, the third chamber 90 and the fourth chamber 92, with the first end 72 and the second end 74 of the shaft 70 spaced from the bottom 64 an equal distance, has an equal preestablished volume. In this application, a first tube 94 of the plurality of tubes or passages 16 for interconnecting the fluid 12 with the free piston pump 14 extends from the source of fluid 12 to a first valve or high pressure valve 96 of the plurality of valve 26. The first valve 96 is of a fast actuating steam or hydraulically driven design. And, a second tube 97 of the plurality of tubes or passages 16 extends from the first valve 96 to a passage 98 of the plurality of tubes or passages 16 extending through one of the pair of covers 50 and exiting the first surface 52 into the first chamber 86. As an alternative the first valve 96 may be attached to the housing 30 thus, eliminating the need for the second tube 97. The first valve 96 is movable between a closed position 100 in which a flow of fluid 12 is prevented from flowing and an open position 102 in which a flow of fluid 12 is allowed to flow. And, further in this application, a third tube 110 of the plurality of tubes or passages 16 for interconnecting the fluid 12 with the free piston pump 14 extends from the source of fluid 12 to a second valve or high pressure valve 112 of the plurality of valve 26. The second valve 112 is of a fast actuating steam or hydraulically driven design. And, a fourth tube 114 of the plurality of tubes or passages 16 extends from the second valve 112 to a passage 116 of the plurality of tubes or passages 16 extending through one of the pair of covers 50 and exiting the first surface 52 into the second chamber 88. As an alternative the second valve 112 may be attached to the housing 30 thus, eliminating the need for the fourth tube 114. The second valve 112 is movable between a closed position 118 in which a flow of fluid 12 is prevented from flowing and an open position 119 in which a flow of fluid 12 is allowed to flow. In this application, the plurality of

tubes or passages 18 for exhausting the fluid 12 includes a third or exhaust valve 120 of the plurality of valve 26 is connected to a fifth tube 122 which is connected to a passage 124. The third valve 120 has a venting or exhaust position 121. The passage 124 extends through one of the pair of end covers 50 and exits the first surface 52, thus being connected to the first chamber 86. As an alternative the third valve 120 may be attached to the housing 30 thus, eliminating the need for the fifth tube 122. A fourth or exhaust valve 126 of the plurality of valve 26 is connected to a sixth tube 128 which is connected to a passage 130. The passage 130 extends through the other one of the pair of end covers 50 and exits the first surface 52, thus being connected to the second chamber 88. As an alternative the fourth valve 126 may be attached to the housing 30 thus, eliminating the need for the sixth tube 128. The fourth valve 126 is of a fast actuating steam or hydraulically driven design. And, the fourth valve 126 has a venting or exhausting position 132.

[20] In this application, the plurality of tubes or passages 20 for transporting a high pressure fluid, hydraulic power 22 exiting from the free piston pump 14 for external use outside the system 6 includes an accumulator 140 being used for high pressure fluid 22, a seventh tube 142 extending from the accumulator 140 to a passage 144. The passage 144 extends through one of the pair of end covers 50 and exits into the third chamber 90 between one of the first end 72 or the second end 74 of the shaft 70 and the bottom 64 of the respective blind bore 62. As an alternative the accumulator 140 may be attached to the housing 30 thus, eliminating the need for the seventh tube 142. A fifth valve or high pressure check valve 148 of the plurality of valves 26 is interposed the accumulator 140 and the third chamber 90. An eight tube 150 extending from the accumulator 140 to a passage 152. The passage 152 extends through the other one of the pair of end covers 50 and exits into the fourth chamber 92 between one of the first end 72 or the second end 74 of the shaft 70 and the bottom 64 of the respective blind bore 62. A sixth valve or high pressure check valve 154 of the

plurality of valves 26 is interposed the accumulator 140 and the fourth chamber 92. A ninth tube 156 communicates the high pressure fluid 22 to one of a plurality of output uses. As an alternative if the accumulator 140 is attached to the housing 30 the need for the eight tube 150 is eliminated.

[21] Further in this application, the plurality of tubes or passages 24 for transporting low pressure fluid 25 for internal use includes an accumulator 160 being used for low pressure fluid 25, a tenth tube 162 extending from the accumulator 160 to a passage 164. The passage 164 extends through one of the pair of end covers 50 and exits into the third chamber 90 between one of the first end 72 or the second end 74 of the shaft 70 and the bottom 64 of the respective blind bore 62. As an alternative the accumulator 160 may be attached to the housing 30 thus, eliminating the need for the tenth tube 162. A seventh valve or low pressure check valve 168 of the plurality of valves 26 is interposed the accumulator 160 and the third chamber 90. An eleventh tube 170 extending from the accumulator 160 to a passage 172. The passage 172 extends through the other one of the pair of end covers 50 and exits into the fourth chamber 92 between one of the first end 72 or the second end 74 of the shaft 70 and the bottom 64 of the respective blind bore 62. An eight valve or low pressure check valve 174 of the plurality of valves 26 is interposed the accumulator 160 and the fourth chamber 92. As an alternative if the accumulator 160 is attached to the housing 30 the need for the eleventh tube 170 is eliminated.

[22] In reference to Figure 2, another version of the system 6 is shown having an alternative free piston pump 14 configuration, common components will retain the same reference numeral, the free piston pump 14 includes the housing 30 defining the first end 32, the second end 34 and at least one side surface 36. A plurality of through bores 180 extend between the first end 32 and the second end 34 and have a preestablished geometrical configuration. A first blind bore 182 extends from one of the first end 32 or the second 34 toward the other respective first end 32 or second end 34 a preestablished distance forming a

bottom 184 of the first blind bore 182. A second blind bore 186 extends from the other of the first end 32 or the second end 34 toward the other respective first end 32 or second end 34 a preestablished distance forming a bottom 188 of the second blind bore 186. The first blind bore 182 and the second blind bore 188 are radially offset one from the other and the bottom 184 of the first blind bore 182 and the bottom 188 of the second blind bore 186 extend axially beyond each other into the housing 30. A plurality of threaded bores 190 extend into the housing 30 from each of the first end 32 and the second end 34. The plurality of threaded bores 190 have a preestablished geometrical configuration. The pair of end covers 50 each define the first surface 52 and the second surface 54 being spaced one from the other a preestablished distance. The plurality of through bores 56, having the same preestablished geometrical configuration of the plurality of threaded bores 190, extend between the first surface 52 and the second surface 54 of each of the pair of end covers 50. The first surface 52 of one of the pair of end covers 50 is in contacting sealing relationship with the first end surface 32 of the housing 30. And, the first surface 52 of the other of the pair of end covers 50 is in contacting sealing relationship with the second end surface 34 of the housing 30. A plurality of fasteners, such as bolts 60 removably attach the respective one of the pair of end covers 50 to the housing 30. As an alternative, a plurality of through bores and bolts or threaded rod could be used in place of the bolts 60 and threaded bores 190 to removably fasten the housing 30 with the pair of end covers 50. As a further alternative, at least one of the pair of end covers 50 could be integral with the housing 30 or fixedly attached thereto. Again, the surface finish of the first end surface 34 of the housing 30 and the first surface 52 of pair of end covers 50 and the second end surface 36 of the housing 30 and the first surface 52 of the pair of end covers 50 respectfully seal the pair of end covers 50 with the housing 30. As an alternative, a gasket may be interposed the pair of end covers 50 and the housing 30. Each of the pair of end covers 50 has a blind bore 62 extending from the first surface 52 toward the second surface

54. The blind bore 62 has a preestablished configuration of which in this application is designed as a diameter. The blind bore 62 and defines a bottom 64. A pair of pistons 76 each define the first surface 78 and the second surface 80. Each of the pair of pistons 76 have a preestablished configuration to match that of the blind bore 62 in each of the pair of end covers 50. A plurality of rods 200 each have a first end 202 and a second end 204. The plurality of rods 200 interconnect the pair of pistons 76 one to the other at each of the first surface 78 and or the second surface 80. A first shaft 206 has a preestablished diameter, a first end 208 and a second end 210. A second shaft 212 has a preestablished diameter, a first end 214 and a second end 216. One of the first shaft 206 and the second shaft 212 has one of the first end 208,214 or the second end 210,216 attached to one of the first surface 78 or second surface 80 of the pair of pistons 76. The plurality of rods 200 are slidably positioned in the plurality of through bores 180, the pair of pistons 76 are slidably positioned in the respective blind bore 62 in each of the pair of end covers 50 and the first shaft 206 and the second shaft 112 is slidably positioned in a respective one of the first blind bore 182 and the second blind bore 186. With the proper fit or clearance no bearing are required; however, if desirable bearing may be added without changing the aspects of the design. The seal 82 is interposed each of the first shaft 206 and the second shaft 212 and the respective one of the first blind bore 182 and the second blind bore 186 near the respective first end surface 32 and the second end surface 34. And, the seal 84 is located intermediate the first surface 78 and the second surface 80 of each of the pair of pistons 76 along the circumferential contour. Thus, with the pair of pistons 76 positioned in the respective blind bore 62, the seal 84 is interposed each one of the pair of pistons 76 and the respective blind bore 62 in the respective one of the pair of end covers 50.

[23] The first chamber 86 is formed between one of the first surface 78 or the second surface 80 of the pair of pistons 76 and the bottom surface 64 of one of the pair of end covers 50 and the second chamber 88 is formed between

the other of the first surface 78 or the second surface 80 of the piston 76 and the bottom surface 64 of the other one of the pair of end covers 50. The third chamber 90 is formed between one of the first end 208 or the second end 210 of the first shaft 206 and the bottom 188 of the second blind bore 186. The fourth chamber 92 is formed between one of the first end 214 and the second end 216 of the second shaft 212 and the bottom 184 of the first blind bore 182.

[24] In this application, the first tube 94 of the plurality of tubes or passages 16 for interconnecting the fluid 12 with the free piston pump 14 extends from the source of fluid 12 to the first valve 96 acting as a high pressure valve of the plurality of valve 26. And, the second tube 97 of the plurality of tubes or passages 16 extends from the first valve 96 to the passage 98 of the plurality of tubes or passages 16 extending through one of the pair of covers 50 and exiting the bottom 64 of the blind bore 62 into the first chamber 86. As an alternative the first valve 96 may be attached to the end cover 50 thus, eliminating the need for the second tube 97. And, further in this application, the third tube 110 of the plurality of tubes or passages 16 for interconnecting the fluid 12 with the free piston pump 14 extends from the source of fluid 12 to the second valve 112 acting as a high pressure valve of the plurality of valve 26. And, the fourth tube 114 of the plurality of tubes or passages 16 extends from the second valve 112 to the passage 116 of the plurality of tubes or passages 16 extending through one of the pair of covers 50 and exiting the bottom 64 of the blind bore 62 into the second chamber 88. As an alternative the second valve 112 may be attached to the end cover 50 thus, eliminating the need for the fourth tube 114. The first valve 96 and the second valve 112 in addition to being movable between a closed position 100,118 in which a flow of fluid 12 is prevented from flowing and an open position 102,119 in which a flow of fluid 12 is allowed to flow is movable into a third position, a venting position or an exhaust position 218, as shown in phantom in Figure 1.

[25] In this application, the plurality of tubes or passages 18 for exhausting the fluid 12 includes the first valve 96 now acting as an exhaust valve of the plurality of valve 26 is connected to the second tube 97 which is connected to the passage 98. The passage 98 extends through one of the pair of end covers 50 and exits the bottom 64 of the blind bore 62, thus being connected to the first chamber 86. As an alternative the first valve 96 may be attached to the end cover 50 thus, eliminating the need for the second tube 97. The second valve 112 now acting as a low pressure valve of the plurality of valve 26 is connected to the fourth tube 114 which is connected to the passage 116. The passage 116 extends through the other one of the pair of end covers 50 and exits the bottom 64 of the blind bore 62, thus being connected to the second chamber 88. As an alternative the second valve 112 may be attached to the end cover 50 thus, eliminating the need for the fourth tube 114.

[26] In this application, the plurality of tubes or passages 20 for transporting a high pressure fluid, hydraulic power 22 exiting from the free piston pump 14 for external use outside the system 6 includes the accumulator 140 being used for high pressure fluid 22, the seventh tube 142 extending from the accumulator 140 to the passage 144. The passage 144 extends through the housing 30 and exits into the third chamber 90 between one of the first end 208 or the second end 210 of the first shaft 206 and the bottom 188 of the second blind bore 186. As an alternative the accumulator 140 may be attached to the housing 30 thus, eliminating the need for the seventh tube 142. The fifth valve or high pressure check valve 148 of the plurality of valves 26 is interposed the accumulator 140 and the third chamber 90. The eight tube 150 extending from the accumulator 140 to the passage 152. The passage 152 extends through the housing 30 and exits into the fourth chamber 92 between one of the first end 214 or the second end 216 of the second shaft 212 and the bottom 184 of the first blind bore 182. The sixth valve or high pressure check valve 154 of the plurality of valves 26 is interposed the accumulator 140 and the fourth chamber 92. The

ninth tube 156 communicates the high pressure fluid 22 to one of a plurality of output uses. As an alternative if the accumulator 140 is attached to the housing 30 the need for the eight tube 150 is eliminated.

[27] Further in this application, the plurality of tubes or passages 24 for transporting low pressure fluid 25 for internal use includes the accumulator 160 being used for low pressure fluid 25, the tenth tube 162 extending from the accumulator 160 to the passage 164. The passage 164 extends through the housing 30 and exits into the third chamber 90 along the bottom 188 of the second blind bore 186. As an alternative the accumulator 160 may be attached to the housing 30 thus, eliminating the need for the tenth tube 162. The seventh valve or low pressure check valve 168 of the plurality of valves 26 is interposed the accumulator 160 and the third chamber 90. The eleventh tube 170 extending from the accumulator 160 to the passage 172. The passage 172 extends through the housing 30 and exits into the fourth chamber 92 along the bottom 184 of the first blind bore 182. The eight valve or low pressure check valve 174 of the plurality of valves 26 is interposed the accumulator 160 and the fourth chamber 92. As an alternative if the accumulator 160 is attached to the housing 30 the need for the eleventh tube 170 is eliminated.

[28] With reference to Figure 3, the system 6 is shown having an alternative free piston pump 14 configuration from that of Figure 2 in that the pair of pistons 76 each have a different diameter. And, a steam reheating system or means for reheating 300 is shown. Common components will retain the same reference numeral. Only the different or added components will be defined and the remaining components are identical to those defined with reference to Figure 2. One of the pair of pistons 76 has a preestablished diameter being less than that of the other one of the pair of pistons 76. The smaller diameter piston will be designated with a primed number 76' and the larger piston 76 will remain void of a prime. A twelfth tube 302 of the plurality of tubes or passages 18 for exhausting the fluid is attached to the first valve 96 at an end and enters an inlet

end 304 of a steam reheating device 306 at another end of the twelfth tube 302. A thirteenth tube 308 of the plurality of tubes or passages 18 for exhausting the fluid extends from the second valve 112 and is attached to the inlet end 304 of the steam reheating device 306. A fourteenth tube 310 of the plurality of tubes or passages 16 for interconnecting the fluid 12 with the free piston pump 14 is attached to an outlet end 312 of the steam reheating device 306 at an end. And, the other end of the fifteenth tube 310 is attached to the second valve 112.

[29] The control system 28 of the system 6, is controlled and functionally operated by a computer or means for computing 330. A plurality of sensors or means for sensing 332 and lines or means for connecting 334 interconnect with the computer 330 in a conventional manner. A portion of the plurality of sensors 332 are positioned on or in operating relationship with each of the valves 96,112,120,126 the chambers 86,88,90,92, the position of the pistons 76,76', the accumulators 140,160, the steam supply 12, the high pressure outlet 156 and the steam reheating device 306.

[30] In Figure 4, a simple Rankin T-s diagram describes the operation of the system 6. The abscissa represents entropy and the ordinate represents temperature. Water in a liquid state, along the x axis the water changes to steam, from liquid to gas. And, along the y axis a change in temperature is represented. For example, points along the graph represent the following: from 1 to 2 represents water being pressurized to achieve a high system pressure; from points 2 to 3 heat is introduced to the pressurized water; from 3 to 4 superheated steam is expanded in the pump 14 and from 4 to 1 steam is condensed.

[31] In Figure 5, a T-s diagram of the proposed steam cycle using the pump 14 of Figure 3 is shown. Again, the abscissa represents water in a liquid state, along the x axis the water changes to steam, from liquid to gas. And, along the y axis a change in temperature is represented. For example, points along the graph represent the following: from 1 to 2 represents water being pressurized to achieve a high system pressure; from points 2 to 3 heat is introduced to the

pressurized water; from 3 to 4 superheated steam is expanded in the pump 14 by the small piston 76'; from 4 to 5 the steam is reheated within the reheating device 306; from 5 to 6 superheated steam is expanded in the pump 14 by the larger piston 76; and from 6 to 7 steam is condensed.

Industrial Applicability

[32] In operation, the present system 6 converts steam power 12 to hydraulic output power 22. Both Figure 1 and Figure 2 show a setup of a free piston pump 14 powered by steam. For example, steam 12 from an external source travels along each of the first tube 94 and the third tube 110 to each of the first valve 96 and the second valve 112 respectively. With the piston or pistons 76 properly positioned a signal is directed from the appropriate sensor 332 and one of the first valve 96 and second valve 112 is moved from the closed position 100,118 into the open position 102,119 and steam is directed to one of the first chamber 86 or the second chamber 88 through the respective combination of the second tube 97 and the passage 98 or the fourth tube 114 and the passage 116. As the piston 76 moves within one of the first chamber 86 and the second chamber 88 the preestablished volume of one chamber 86,88 increases whereas the preestablished volume of the other chamber 88,88 decrease. For example, if the first surface 78 moves toward the first surface 52 the volume within the first chamber 86 decreases and the volume within the second chamber 88 increases.

[33] For example in Figure 1, as determined by the plurality of sensors 332 and with the signal directed to the computer 330 by the plurality of wires 334 and directed by the computer 330 to the appropriate one of the plurality of valves 26, if the second surface 80 of the piston 76 is closest to the first surface 52 of the end cover 50, steam 12 enters the second chamber 88 and moves the piston 76 and the first end 72 of the shaft 70 axially into the third chamber 90 attempting to compress the volume of oil therein and opening the fifth valve 148 causing a flow of pressurized hydraulic oil 22 to enter the high pressure accumulator 140. The oil passes through the passage 144 through the seventh tube 142 and the fifth

valve 148 into the high pressure accumulator 140 to be used externally of the system 6. And, as the second end 74 of the shaft 70 moves axially out of the fourth chamber 92 increasing the volume within the fourth chamber 92 oil 25 is drawn from the low pressure accumulator 160 through the eight valve 174, a check valve, through the eleventh tube 170 into the passage 172 and into the fourth chamber 92 refilling the fourth chamber 92 with fluid or oil 25.

[34] If on the other hand in Figure 1, as determined by the plurality of sensors 332 and with the signal directed to the computer 330 by the plurality of wires 334 and directed by the computer 330 to the appropriate one of the plurality of valves 26, if the first surface 78 of the piston 76 is closest to the first surface 52 of the end cover 50, steam 12 enters the first chamber 86 and moves the piston 76 and the second end 74 of the shaft 70 axially into the fourth chamber 92 attempting to compress the volume of oil therein and opening the sixth valve 154 causing a flow of pressurized hydraulic oil 22 to enter the high pressure accumulator 140. The oil passes through the passage 152 through the eight tube 150 and the sixth valve 154 into the high pressure accumulator 140 to be used externally of the system 6. And, as the first end 72 of the shaft 70 moves axially out of the third chamber 90 increasing the volume within the third chamber 90 oil 25 is drawn from the low pressure accumulator 160 through the seventh valve 168, a check valve, through the tenth tube 162 into the passage 164 and into the third chamber 90 refilling the third chamber 90 with fluid or oil 25.

[35] For example in Figure 2, as determined by the plurality of sensors 332 and with the signal directed to the computer 330 by the plurality of wires 334 and directed by the computer 330 to the appropriate one of the plurality of valves 26, if the second end 210 of the first shaft 206 is closest to the bottom 188 of the third chamber 90 steam 12 enters the second chamber 88 and moves the piston 76 and the first end 214 of the second shaft 212 axially into the fourth chamber 92 attempting to compress the volume of oil therein and opening the sixth valve 154 causing a flow of pressurized hydraulic oil to enter the high pressure accumulator

140. The oil passes through the passage 152 through the eight tube 150 and the sixth valve 154 into the high pressure accumulator 140 to be used externally of the system 6. And, as the second end 210 of the first shaft 206 moves axially out of the third chamber 90 increasing the volume within the third chamber 90 oil is drawn from the low pressure accumulator 160 through the seventh valve 168, a check valve, through the tenth tube 162 into the passage 164 and into the third chamber 90 refill the third chamber 90 with fluid or oil 25.

[36] If on the other hand in Figure 2, as determined by the plurality of sensors 332 and with the signal directed to the computer 330 by the plurality of wires 334 and directed by the computer 330 to the appropriate one of the plurality of valves 26, if the first end 214 of the second shaft 212 is closest to the bottom 184 of the fourth chamber 92, steam 12 enters the first chamber 86 and moves the piston 76 and the second end 210 of the first shaft 206 axially into the third chamber 90 attempting to compress the volume of oil therein and opening the fifth valve 148 causing a flow of pressurized hydraulic oil 22 to enter the high pressure accumulator 140. The oil passes through the passage 144 through the seventh tube 142 and the fifth valve 148 into the high pressure accumulator 140 to be used externally of the system 6. And, as the first end 214 of the second shaft 212 moves axially out of the fourth chamber 92 increasing the volume within the fourth chamber 92 oil 25 is drawn from the low pressure accumulator 160 through the eight valve 174, a check valve, through the eleventh tube 170 into the passage 172 and into the fourth chamber 92 refilling the fourth chamber 92 with fluid or oil 25.

[37] In operation, the present system 6 converts steam power 12 to hydraulic output power 22. Figure 3 shows a setup of a free piston pump powered by steam in which the pistons 76,76' are of different sizes. For example, steam 12 from an external source travels along each of the first tube 94 and the third tube 110 to each of the first valve 96 and the second valve 112 respectively. With the piston or pistons 76,76' properly positioned a signal is

directed from the appropriate sensor 332 and one of the first valve 96 and second valve 112 is opened and steam is directed to one of the first chamber 86 or the second chamber 88 through the respective combination of the second tube 97 and the passage 98 or the fourth tube 114 and the passage 116.

[38] For example in Figure 3, as determined by the plurality of sensors 332 and with the signal directed to the computer 330 by the plurality of wires 334 and directed by the computer 330 to the appropriate one of the plurality of valves 26, if the second surface 80 of the piston 76 is closest to the bottom 64 of the blind bore 62 in the end cover 50, steam 12 enters the second chamber 88 and moves the piston 76' and the first end 214 of the second shaft 212 axially into the fourth chamber 92 attempting to compress the volume of oil therein and opening the sixth valve 154 causing a flow of pressurized hydraulic oil 22 to enter the high pressure accumulator 140. The oil passes through the passage 152 through the eight tube 150 and the sixth valve 154 into the high pressure accumulator 140 to be used externally of the system 6. And, as the second end 210 of the first shaft 206 moves axially out of the third chamber 90 increasing the volume within the third chamber 90 oil 25 is drawn from the low pressure accumulator 160 through the seventh valve 168, a check valve, through the tenth tube 162 into the passage 1164 and into the third chamber 90 refilling the third chamber 90 with fluid or oil 25.

[39] If on the other hand in Figure 3, as determined by the plurality of sensors 332 and with the signal directed to the computer 330 by the plurality of wires 334 and directed by the computer 330 to the appropriate one of the plurality of valves 26, if the second surface 80 of the piston 76' is closest to the first bottom 64 of the blind bore 62 of the end cover 50, steam 12 enters the first chamber 86 and moves the piston 76' and the second end 208 of the first shaft 206 axially into the third chamber 90 attempting to compress the volume of oil therein and opening the fifth valve 148 causing a flow of pressurized hydraulic oil 22 to enter the high pressure accumulator 140. The oil passes through the

passage 144 through the seventh tube 142 and the fifth valve 148 into the high pressure accumulator 140 to be used externally of the system 6. And, as the first end 72 of the second shaft 212 moves axially out of the fourth chamber 92 increasing the volume within the fourth chamber 92 oil 25 is drawn from the low pressure accumulator 160 through the eight valve 174, a check valve, through the eleventh tube 170 into the passage 172 and into the fourth chamber 92 refilling the fourth chamber 92 with fluid or oil 25.

[40] Unlike the steam expander, the free piston pump 14 does not require steam of quality 1. The steam is expanded until the quality drops below 1 into the region of saturated vapor adding to the potential efficiency of the free piston pump 14 by extracting more energy from the steam power source.

[41] The free piston pump 14 is a double acting pump in which steam power is injected on one side of the piston 76,76' and automatically resets the opposing piston 76,76' for steam injection into the appropriate chamber 86,88.

[42] Removal of saturated steam and water is key to the functionality of the free piston pump 14. The exhaust valves 94,112 is a fast actuating steam or hydraulically driven valve that opens to one of the chambers 86,88 and the piston 76,76' returns and purges the combination of saturated steam and water form the chamber 86,88.

[43] In Figure 2 the exhaust valves 94,112 is a special 3-way valve which can switch from steam supply to exhaust, thus taking the place of two individual valves. Figure 2 also shows opposed pistons 76 verses a single piston as shown in Figure 1.

[44] As shown in Figure 3, to extract as much energy as possible the combination of the smaller piston 76' and the large piston 76 is shown. For example, steam is introduced into the first chamber 86. This expands the first chamber 86 performing hydraulic work and causing the steam to be at a significantly lower pressure. This resets the larger piston 76 for an expansion stroke. To extract as much energy as possible from the lower pressure steam in

chamber 86, the steam is transferred through a reheating device 306 and into the second chamber 88. Within the second chamber 88 the larger piston 76 is expanded and more energy is extract to do more work increasing efficiency of the system 6. For example, with the computer 330 operating as defined above and as further defined herein, the flow of steam 12 is directed through the first tube 94 into the first valve 96 and through the second tube 97 and the passage 98 into the first chamber 86. The steam 12 expands the piston 76' and the spent steam 25 is transferred to the steam reheating device 306 through the twelfth tube 302. The steam 12 is reheated within the reheating device 306 and exits through the fourteenth tube 310 to the second valve 112. From the second valve 112 the steam 12 is transferred through the fourth tube 114 and the passage 116 into the second chamber 88 wherein the steam expands the larger piston 76. And, as stated above, causes the hydraulic fluid, oil, within the fourth chamber 92 to be pressurized and flow to the high pressure accumulator 140. The spent steam 12 from the second chamber 88 can also be transferred to the reheating device 306, reheated and used again. To transfer the spent steam 25 from the first chamber 86 high pressure steam 12 is directed to the second valve 112 from the steam power source as described above.

[45] Thus, a system 6 is provided which utilizes a quantity of steam having a quality below 1 to operate a free piston pump 14. The free piston pump 14 is highly efficient and has a double acting pump operation. As an alternative, the free piston pump 14 can be used individually or in combination one with another such as by stacking.